Some Recent Advances in Insecticides

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(Presidential Address, presented at the meeting of Dec. 9, 1940)*

The introduction of agricultural plants into a new environment is often followed by the invasion of insect pests either from wild hosts or from regions where the introduced plants were cultivated as an economic crop. The movement of an insect pest from its wild host to a cultivated one, or from one cultivated crop to another, is an old story. Man, in order to protect his crops, has made use of biological, mechanical or chemical methods for the destruction of insect pests.

Biological control may be considered the ideal method of control of an insect population. After the introduction process has been accomplished, the introduced species establishes its own population which in turn rises and falls as its host increases or decreases in population magnitude. Where agricultural crops of long duration are infested with an insect pest, then the introduced parasitic species may prove successful provided the physical environment is favorable for the reproduction of the parasite. The effect of the parasitic biotic resistance on the reproductive potential of the insect pest should be shown before the crop is harvested. Such an illustration has been amply demonstrated by the introduction of parasites into the Hawaiian Islands for insect pests of host crops, the planting of which is continuous over a period of years. Sometimes, the physical nature of the host plant involved is such as to impede the control which normally the introduced species would have upon its insect host. The Mediterranean fruitfly (larval stage) in coffee is highly parasitized, while the physical environment of the maggot in fleshy fruits gives some protection against parasitization.

So, when the agricultural crops in question are of short duration or the environment of the susceptible stage of the insect to biological control interferes, the setting up of a biotic resistance in the form of either parasite or predator may not prove successful due to the fact that the insect pest has destroyed the crop before its population can be reduced to the minimum where its presence does not seriously affect production. Then, there must be taken into consideration other means of insect pest control, which may be mechanical or chemical.

Mechanical control has been advocated and used successfully to

* This paper was not available for printing at the time the Proceedings for 1940 was printed. [Ed.]

destroy certain insects at some stage in the life cycle. Mechanical control may aid in controlling an insect pest but may not be practical as the only method for the reduction of an insect population to the minimum which may be necessary for good crop protection.

Chemical control of insect populations has been advocated and carried on in all agricultural regions especially where (1) the physical environment is such that biological control is not practical, (2) the location of the susceptible stage in the life cycle of the insect pest is protected by its environment from biological or mechanical destruction, (3) a parasite or predator for the insect pest has never been found, (4) the destruction of the entire population of the insect pest must be accomplished, (5) chemical control is more economical.

In Hawaii the environment is such that an insect may multiply rapidly with a minimum of physical resistance. The intense interest and experimentation in diversified agriculture in these islands due to the defense program, means that the entomologists here will be called upon to control a greater number of insect pests of additional economic crops. Therefore, the writer considers the time opportune for the presentation of a brief discussion on the recent developments in insecticides.

ARSENICALS

Insect toxicologists have used and continue to use lead arsenate not only as an insecticide but as a basis by which the toxicity of other chemical compounds may be compared. Because of the injury to some plants by water soluble arsenical compounds an extensive study has been made on the decomposition of acid lead arsenate in spray residues. The ratio of lead to arsenious oxide in pure acid lead arsenate is 2.09: 1, whereas in spray residues ratios as high as 9: 1 have been reported in the literature. The view has been held that the arsenic in spray residues weathers away more rapidly than the lead and that the acid lead arsenate undergoes gradual decomposition toward the more basic compounds of lead and arsenic. However, Fahey and Rusk [36†] in their work on the problem report findings contradictory to the results of earlier investigators. Samples of sprayed fruit and foliage were gathered for analysis from apple orchards immediately after spraying and again within a few days to as late as 75 days following applications. A total of 248 samples of apples and apple foliage were used. They state that the average ratio of lead to arsenious oxide in these samples did not vary significantly from that in the original spray material and that the high ratios obtained by earlier investigators are due probably to inadequate samples or to unreliable methods of analysis.

Ginsburg and Perlgut [44] found that small quantities of hydrogen sulfide decompose acid lead arsenate, forming large amounts of

† Numbers refer to the papers in the list of Literature.

soluble arsenic. Decomposition by hydrogen sulfide may be prevented by the addition of an excess of calcium hydroxide, as calcium hydroxide readily reacts with hydrogen sulfide, changing it to calcium sulfide. Some of the common sources of hydrogen sulfide are stagnant water and sulfur fungicides.

One of the new combinations of arsenic is a basic copper arsenate Cu (Cu OH) AsO_4 which has been presented in the literature by Witman et al [125] and Waters et al [122]. Basic copper arsenate is a definite crystalline chemical compound and is very insoluble in water; it is not subject to hydrolysis and is decomposed but little by carbon dioxide; it is compatible with lime, calcium caseinate, sulfur, Bordeaux mixture and sodium chloride solutions. Basic copper arsenate was fully as effective against Mexican bean beetle, Colorado potato beetle, and a number of other insects as acid lead arsenate or calcium arsenate. The insecticide has a slower initial effect and a more rapid final effect than lead arsenate which thus increases the chance that a toxic dose is obtained before feeding is inhibited.

In further work, Ellisor and Floyd [33] found basic copper arsenate gave a good control of the velvetbean caterpillar and exhibited unusual sticking properties without damaging soybean foliage. Felt and Bromley [38] found the material gave protection from the attacks of the black walnut caterpillar, the hickory tussock caterpillar and the fall webworm as well as a satisfactory control for the walnut leaf spot disease. However, on other pests the insecticide was not as effective and some injury of the type produced by copper occurred on fruit and foliage of apple trees.

The limited use of calcium arsenate as an insecticide has led to a further search for calcium arsenates of greater stability and uniformity. Nelson [89] found that the large percentage of water-soluble arsenic in some commercial insecticidal calcium arsenate is due to the presence of dicalcium arsenate. By atomizing a dilute solution of arsenic acid into a suspension of hydrated lime under conditions whereby the ratios of the reactants were adjusted, a product was produced which was less acid than tricalcium arsenate. Calcium arsenates of any desired composition, up to a CaO : As_2O_5 ratio of approximately 3.8 can be prepared by adjusting the ratio of the reacting substances.

Bulger and Nelson [13] tested a series of these calcium arsenates for toxicity to silkworm larvae. The hydrous arsenates which ranged from $CaO.As_2O_5.2H_2O$ to 4 $CaO.As_2O_5.XH_2O$, were fairly toxic while the anhydrous compounds of like series were nontoxic to the extent that no M. L. D. range was established. The hydrous tri- and tetracalcium arsenates were only about half as toxic as the mono and dicalcium compounds. The toxicity of the latter two arsenates were about equal, notwithstanding the fact that the amount of soluble arsenic present varied greatly. The toxicity of the compounds to bean plants paralleled that to the larvae.

The results of the heat treatments of calcium arsenate suggest that the toxicity balance of these arsenates is rather delicate and that care in preparation should be exercised if the toxicity is to be maintained.

Hastings and Pepper [65] report dusts formed by mixing sodium arsenite with inert materials such as calcium carbonate, bentonite, volcanic ash, hydrated lime, were effective in treating Mormon crickets when applied either as purely contact poisons or as stomach and contact poison combined. Increase of temperature caused a decrease in the time to reach 50 percent mortality of both nymphs and adults; the degree of correlation was the higher in the case of the adults.

ARSENICAL SUBSTITUTES

Since the use of arsenic compounds as insecticides is restricted because of the arsenic and lead tolerance as well as possible injury to plant foliage, more investigators are turning their attention to other chemical compounds which may have possibilities as insecticides. Among these are the fluorine compounds, plant alkaloids, potassium antimony tartrate, organic compounds, and a number of other materials.

Chang and Campbell [22] in their recent study on the toxicology of phosphorus with respect to insects, found phosphorus was much more toxic to the American cockroach than sodium arsenite or sodium fluoride. Injection of roaches with a physiological salt solution containing phosphorus caused death, but proved less toxic than when the solution was administered by mouth. Cockroaches died when confined with phosphorus in a small closed place and the insecticide proved toxic when painted on the body of the animal. The toxic action may have been due to the action of the phosphorus vapor, or to a depletion of oxygen by oxidation of the phosphorus, or to desiccation of the insect by the oxides of the phosphorus.

Of a number of stomach poisons tested by Travis [115] for control of the fire ant, only thallium sulfate and thallium acetate were successful. Many of the compounds produced repellancy while others, although fed upon, were not highly toxic. Among the latter were the arsenates, fluorides, borax, barium chloride and tartar emetic.

Boyce and Persing [11] report promising results with tartar emetic either in dust form or in a sweet spray as a control for thrips on lemons. Anderson and Walker [2] in greenhouse tests controlled thrips on onion plants with tartar emetic-brown sugar solutions. However, control was not as good under field conditions. One application of the tartrate spray on snap beans heavily infested with onion thrips reduced the number of nymphs by more than 97 percent and prevented reinfestation for at least 7 days. Johnson and

Smith [70] found a calcium antimony tartrate spray gave results comparable with those for a tartar emetic spray of equal antimony content as a control for the gladiolus thrips. Weigel and Johnson [123] report the control of the common red spider on carnation cuttings by spraying with a tartar emetic-brown sugar solution. However, they recommend the substitution of glycerin for sugar as the glycerin eliminates the sticky sugar residue without reducing the toxicity of the spray.

The fluorine compounds as insecticides have received a great deal of attention during the last few years. Of the more recent work, Baker and Questel [8] investigated sodium fluoaluminate and a calcium fluosilicate compound for controlling the European corn borer. These materials when applied in spray form were effective and ranked about equal with derris, but as dusts were not so effective. The fluorine compounds caused more or less injury to the plants, which makes their use undesirable unless some means can be devised to eliminate their burning effects. Lincoln and Palm [77] report that the raisin-shorts-sodium fluosilicate bait still remains the best bait used in control of the alfalfa snout beetle. However, considering the ease of application and availability of materials, corncob, sugar and soybean flour may be substituted for the raisin-shorts without a decrease in toxicity. Ritcher [97] in his study of poison baits for strawberry crown borer control in Kentucky, observed that a commercial sodium fluosilicate mixed with an apple bait gave as high as 84.3 percent control of the adults in fields not surrounded by barriers.

In South Carolina, Rainwater [95] found finely ground cryolite, containing 90.8 percent of sodium fluoaluminate, when mixed with an adhesive agent, was comparable to calcium arsenate as a control for the boll weevil. However, both Gaines [41] in Texas and Young et al [129] in Louisiana observed that calcium arsenate and calcium arsenate plus sulfur were superior to cryolite as a boll weevil insecticide. Gaines found a special calcium arsenate containing large particles and a high percentage of water soluble arsenic pentoxide gave a significantly better control of both the weevil and the rapid plant bug than commercial calcium arsenate.

Carter [17] in his recent work examined 18 samples of commercial cryolites for the moisture and sodium fluoaluminate content. He discussed the particle size distribution from determinations by the sedimentation method. Goodhue and Gooden [46] describe a microprojection method and an improved sedimentation method for determining particle size distribution of insecticide materials, the latter method being favored due to the comparative ease with which results may be obtained.

The relationship between particle size and toxicity of stomach poisons has been food for thought and discussion among toxicologists. Siegler and Goodhue [102] conducted tests under controlled laboratory conditions on the effect of particle size on the toxicity of five insecticides to codling moth larvae. Coarse particles of lead arsenate were somewhat more effective than the fine fraction. The medium fraction of calcium arsenate was more toxic than the fine or coarse particles, however, the three fractions were not of uniform chemical composition. The coarse fraction of phenothiazine was less toxic than the medium and fine fractions, yet the chemical composition of the three fractions were quite similar. In the case of Paris green and cryolite the middle size particles were more toxic yet the chemical analysis of the three fractions of each insecticide was approximately the same. This work suggests that particle size is an important consideration in the effectiveness of stomach poisons and that extremely small particles in an insecticide may not always be desirable.

In the search for organic compounds to replace the arsenicals now employed for the control of the codling moth, Siegler, Munger and Smith [103] tested over 200 compounds. Para-iodonitrobenzene was found to have high initial toxicity. In further work [104] the toxicity of certain benzene derivatives containing the halogen and nitro groups to codling moth larvae was determined. P-iodonitrobenzene, m-iodonitrobenzene, p-bromonitrobenzene and m-dinitrobenzene gave an initial toxicity of less than 50 percent wormy plugs, while in residual tests, the p-iodonitrobenzene lost most of its effectiveness in five or six days. There was no marked correlation found between either the groupings involved or their relative positions in the molecule, with regard to their toxicity to the codling moth larvae. However, Bushland [14, 15] in recent papers, states that p-iodonitrobenzene is non-toxic to the screwworm and that the alteration of the molecule in some of the compounds influenced toxicity, but no simple relationship existed between chemical constitution of an organic compound and its toxicity to screwworm larvae. Bushland lists over 550 organic compounds which were compared with phenothiazine and rotenone as insecticides. Of the 77 compounds which showed outstanding toxicity, 10 were less toxic than rotenone, 25 were equal to rotenone, 31 were equal in toxicity to phenothiazine and 11 were more toxic than phenothiazine. Of the latter 11 materials, 10 were compounds bearing the nitro group. Phenothiazine has been reported [85] as an insecticide for prevention of reinfestation of wounds on cattle by screwworm flies.

PLANT POISONS

Nicotine, either in free form or as a sulfate, has been known and used as a contact insecticide. However, in the last few years, other salts of this plant alkaloid have been prepared and tested as possible stomach poisons. Batchelder [5] in a recent publication describes a new form of nicotine-tannic acid product for controlling the European corn borer. The product, made from nicotine and extract of quebracho wood, contains 4.35 percent nicotine, 26 percent quebracho tannins, 15 percent isopropyl-alcohol and the rest various extractive substances and water. The mixture is a thick paste, stable, convenient to handle and comparable to derris in effectiveness against the corn borer.

Pyrethrum is used as a contact insecticide but it has not been found very effective as a stomach poison. Woke [126] in a recent contribution on the subject found that the pyrethrins are inactivated wholly or in part after ingestion by the southern armyworm. The incubation of pyrethrum with the fat body and skin and muscle tissue produced the greatest reduction in toxicity, while blood, digestive tract tissue and contents of the digestive tract were much less effective in the reduction. Woke suggested that some of these tissues or their products may be responsible for the inactivation which occurs in living larvae and that it is doubtful that the tissues or secretions of the digestive tract are alone responsible. Böttcher [8, 9] of Germany has recently compared pyrethrum and derris as stomach and contact poisons on the honey bee. Both compounds were found to be toxic internally and externally. Within certain limits the toxic action of only pyrethrum was decreased by increasing temperature.

From the standpoint of chemistry, Graham [50, 52] reviewed the methods for determining pyrethrins in pyrethrum products; Gertler and Haller [43] examined the methods for preparation of kerosene-pyrethrum sprays. Martin and co-workers [83] in England, report on the fertilizer requirements for the growth of pyrethrum plants of high insecticidal value. Harvill [64] combined various compounds with chrysanthemum monocarboxylic acid, the acidic portion of the ester, pyrethrin I. Of the twenty-two esters prepared the most toxic and comparable with the unaltered pyrethrins in efficiency against *Aphis rumicis,* were the lauryl, myristyl, cetyl, and diethanolamine esters. None of the esters produced the typical pyrethrin action when applied to various parts of the cockroach. The stability of the compounds in respect to decomposition and loss of toxicity after six months suggests that the instability of the pyrethrins is due to the ketonic alcohol, pyretholone. Trusler [117] reports on prolonging the toxicity of pyrethrum insect sprays in storage, by excluding the air or by adding an antioxidant.

Of the recent contributions on the use of the pyrethrins, Gnadinger and co-workers [45] use pyrethrin-oil spray for controlling pupae and overwintering larvae of the codling moth, pyrethrum dust, in conjunction with oil sprays, for control of adult moths and eggs. Thus, the codling moth is attacked in every stage of its life history. Walker and Anderson [119, 120] in Virginia controlled the Hawaiian beet webworm on spinach with a pyrethrum dust such as Pyrocide or a pyrethrum powder diluted to contain 0.2 percent pyrethrins. For best results, the dust should be applied when plants are dry.

Calcium arsenate and rotenone bearing dusts were ineffective. In Idaho, Coon and Wakeland [26] in their work on the repellency of pyrethrin dust, found commercial pyrethrum mixtures incorporated in diatomaceous earth were effective in entirely preventing the feeding of *Eutettix tenellus* on tomatoes for 72 to 96 hours in the greenhouse. Because of climatic factors the treatment was not so effective in the field. Barber [4] increased the effectiveness of a light mineral oil for controlling the corn earworm on sweet corn by the addition of one percent pyrethrin.

During the last two years a number of publications have appeared on the chemistry and insecticidal use of derris, cube and related products. Harper [62] isolated from the roots of *Derris elliptica* a new compound (named elliptone) with the formula $C_{20}H_{16}O_6$ and a molecular weight of 352. H. A. Jones [71] found small quantities of an alkaloid in cube and timbo roots; the alkaloid being nontoxic to mosquito larvae at a dilution of 1 : 10,000. Graham [51] describes an improved method for the analysis of rotenone in derris and cube powders, and Jones [72] contributes a review of the colorimetric tests. Goodhue and Haller [47] advance a new method for the determination of deguelin in derris and cube. Martin [82] evaluates varieties of derris, toxicologically by *Aphis rumicis* and chemically by the determination of the percentage "rotenone equivalent" which is based upon the alkaline fractionation of the resins and the toxicities of the deguelin and toxicarol fractions relative to that of rotenone. Tattersfield and Potter [113] report plants of the genus *Annona* possess contact insecticidal properties to aphids. *A. reticulata* was the most potent of those tested but was much less toxic than *Derris elliptica* root.

Allen and Brooks [1] of Wisconsin report on the effect of around thirty-five dust diluents on the toxicity of rotenone-bearing roots to houseflies. The range of the pH values of the various dust diluents was from 4.23 to 12.50. Damp storage for seven days caused a decrease in the pH of the rotenone-bearing roots without and with some of the diluents. A few of the final dust mixtures had pH values greater than those of either the insecticide or the diluent. This may have been caused by some reaction in which more hydroxyl-ions were liberated, giving rise to a more alkaline reading. Rotenone-highly alkaline dusts, after damp storage, exhibited little or no change in pH, but showed considerable loss in toxicity when used in kerosene extracts in tests with houseflies. Parallel acid dust mixtures retained their toxicity to the housefly. Sulfur prevented the deterioration of the rotenone-bearing alkaline dust mixtures.

Chisholm [24] studied the effect of light and temperature on the decomposition of derris. Sievers and Sullivan [105] found no marked differences in the toxicities of several extracts from roots of *Tephrosia virginiana*, a rotenone-bearing plant. Sullivan and coworkers [109] have recently tested a number of the optically active and inactive compounds of the rotenone series as contact poisons on the adult housefly. The type of solvent influenced results. In acetone solution the racemic compounds were much less toxic than the optically active ones, but when tested in highly refined kerosene containing cyclohexanone, the toxicity of the two groups was approximately the same.

Sullivan, Goodhue and Fales [110] describe a new method of dispersing pyrethrum and rotenone in air. The dispersion apparatus consisted of a small atomizer with nozzle mounted seven inches above the center of an electric hot plate held at approximately 375°C. The toxicity tests were made in an 1100-cubic foot furnished room held at 28°-30°C. Seventy-two hours after spraying with pyrethrum oleoresin or rotenone in a safrol solvent, the mortality of houseflies was 74 or more percent. The combination of the two insecticides caused 95 per cent mortality. The aerosol was nontoxic to the American cockroach. An ethyl alcohol solution of pyrethrum caused 99 percent mortality of adult *Culex* mosquitoes after a 10 minute exposure.

English [34, 35] states that derris is a true toxicant for citrus whitefly and purple scale. Derris was effective for control of these insects when used in an oil emulsion spray. Gray and Schuh [55] found rotenone dust with a wetting agent, nicotine dust, pyrethrum dust and nicotine-oil dust controlled the pea aphid. However, the latter treatment was superior to the other dusts. Ditman and coworkers [30] found dusts to be slightly better than sprays in their work on control of the same insect. Derris appeared to be superior to ordinary cube. The factors of cube particle size, humidity, temperature and plant dryness at time of application influenced toxicity. Hamilton [60] has reported that cube root and phenothiazine reduced heavy populations of cherry fruitflies when at least three spray applications were made.

OTHER CONTACT POISONS

The nitrophenols, which fall in the category of contact poisons, have been receiving considerable attention. The work on 3:5-dinitro-o-cresol in dormant sprays [42, 63] has been continued. This compound has been used as an ovicide against mites and aphids, and as a control for certain insect pests of fruit trees. Hough [69] found the compound comparable to coal-tar distillate for aphid eggs. Worthley and Steiner [128] reported the sodium salt of this nitrophenol appeared only slightly toxic to eggs of the European red mite, while Felt and Bromley [38] state that a commercial preparation containing a salt of dinitro-cresylate gave good control of the eggs of the spruce red mite, European red mite, the spruce gall aphid and the oyster shell scale. Shaw and Steer [99] tested 44 organic preparations as ovicides. The 3:5-dinitro-o-cresol was highly toxic to the aphid and red spider eggs but less toxic to eggs of two species of moths. Other effective ovicides were n-dodecyl thiocyanate, B-butoxy-B′-thiocyanodiethyl ether, and nicotine.

Callaway and Musgrave [16] found B-butoxy-B′-thiocyanodiethyl ether to be superior to some other liquid organic insecticides as an ovicide for eggs of *Cimex lectularius*. In further work, Potter and Musgrave [93] state that this thiocyanate has distinct possibilities of becoming an industrial insecticide. The insecticide appeared to be particularly toxic to the eggs of the bedbug, grain weevils and a number of pests of stored agricultural products. Boyce et al [10] have produced promising results with dusts made by diluting dinitro-o-cyclohexylphenol with walnut shell flour. The compound may be applied to citrus and other subtropical plants with greater safety as a dust than as an aqueous dispersion. Morrison and Mote [86] found this nitrophenol in dust form controlled the common red spider on hops. Rotenone, pyrethrum and nicotine sulfate, although compatible when added to the dust, did not contribute to added toxicity. Grayson [56] found the ovicidal effectiveness of petroleum oil against European red mite eggs was slightly increased by the addition of dinitro-o-cyclohexylphenol although this compound when used as a wettable powder without the oil was ineffective as an ovicide.

The wetting, spreading and adherent properties of sprays are being continuously investigated by entomologists. Cupples [28] in a continuation of previous work [27] reports on inorganic salts as adjuvants for increasing wetting power. The addition of chlorides of calcium, magnesium or sodium to solutions of a sulfonated ester of dicarboxylic acid, produced significant increases in wetting power, as measured by surface tension or by spreading coefficient on mineral oil.

Brown and Hoskins [12] show that the pH of spray water has an important relation to the amount of oil deposited by petroleum oil emulsion. Wampler and Hoskins [121] discuss the electric charge on the spray droplets in relation to spray deposits. In a recent paper Upholt and Hoskins [118] present the design and use of a photographic apparatus for studying the impact and movement of individual drops upon a surface. Hensill and Tihenko [67] have studied some of the mechanical and other factors affecting oil spray deposits.

REPELLENTS AND LURES

Investigators have continued their work on the problem of mosquito control and repellents. Powers and Headlee [94] state petroleum oils kill the eggs of *Aedes aegypti* L. by depriving the eggs of oxygen, thus causing suffocation. The ovicidal efficiency of petroleum oils was affected by viscosity and egg coverage. Murray [87] has contributed a publication on the efficiency of petroleum oils as mosquito larvicides.

In the search for chemicals possessing mosquito repellent properties MacNay [80] found the essence of thyme and geranium, cinnamic aldehyde, cresol and some tar distillate fractions were repellent to mosquitoes. A large number of organic compounds have been tested by Granett [53, 54] at Rutgers University. In recent papers the method of testing and evaluating mosquito repellents are described. Out of nearly one thousand materials, a repellent product was developed, which consisted of diethylene glycol monobutyl ether acetate, diethylene glycol monoethyl ether, ethyl alcohol, corn oil, and perfume. The mixture is harmless to all fabrics except acetate rayon. In tests against black flies, sand flies, deer flies and chiggers, frequent applications of the repellent were necessary; however, the mixture had the same relative order of superiority over the other materials. Kilgore [75] has found diethylene glycol monobutyl ether acetate to be repellent to house flies.

Using a new type of olfactometer, Wieting and Hoskins [124] reported that female house flies are attracted to ammonia and males to alcohol, whereas carbon dioxide was not attractive to either sex. Eagleson [32] described the construction and use of an olfactometer for muscoid flies and discussed a method for interpreting results. According to Deonier [29] blowflies were found to have on the tarsi and proboscis, gustatory chemo-receptors through which non-volatile substances can be detected. The flies were strongly repelled by mercuric chloride solutions.

Marlowe [81] tested a number of mixtures as deterrents to the melonfly. Nicotine sulfate plus either Bordeaux mixture or red cuprous oxide gave best results as represented by increase in production of non-infested cucumbers. Ferguson [39] in his studies on coal tar insecticides found calcium pitchate and copper pitchate to be repellent to Mexican bean beetle larvae. The latter compound in effectiveness was comparable to 0.75 percent rotenone dust and cryolite dust. Guy and Dietz [58] and Pierpont [91] have discussed the repellent efficiency of tetramethylthiuram disulfide; this compound being more repellent than derris to the Japanese beetle. Fleming and Burgess [40] working on the attractiveness of geraniol and eugenol to this beetle found an almost equal mixture of the two chemicals was more attractive than either of the baits alone.

Some investigators have added sweet substances as feeding attractants to stomach poisons. Siegler [101] observed that under laboratory conditions, the addition of brown sugar to lead arsenate, calcium arsenate, nicotine bentonite, and phenothiazine increased the toxicity of these insecticides to codling moth larvae. Sucrose, corn syrup, d-fructose, glycerine, and malic acid improved the effectiveness of lead arsenate. The addition of the larval attractant to the insecticide caused a marked reduction in percentage of stings, thus indicating that a higher percentage of the larvae ingested a toxic dose before they ruptured the skin of the apple than when the attractant was not used with the poison.

Of the recent papers on attractants, McPhail [84] reported that proteins in the presence of sodium hydroxide solution made very satisfactory field lures for the Central American fruitfly, and Travis [116] observed that isoamylamine was attractive to male June beetles. Götz [48] found the scent of unfertilized females of two species of the European vine moth to be attractive to the males. Traps containing unfertilized females caught a much greater number of males than the most effective bait hitherto known. Unfertilized females remain attractive throughout their life, the scent being stronger the second day after emergence. There is a possibility of using the sex scent in control as the males generally appear before the females. For practical work it will be necessary to produce the scent synthetically.

FUMIGANTS

Considerable experimental work has been conducted to determine the action of various fumigants on the different stages of insects. Gunderson and Strand [57] found hydrogen cyanide to be more toxic to all stages of the bedbug than ethylene oxide or chloropicrin. The eggs were less resistant to hydrogen cyanide and ethylene oxide than were nymphs and adults, while the reverse was true of chloropicrin. The nymphs and adults were similar in their reactions to each fumigant. However, Gough [49] observed the order of resistance of the confused flour beetle to hydrogen cyanide to be: pupae, adult, larva and egg. It was found that the offspring of resistant individuals was significantly more resistant than the offspring of susceptible individuals, and that this difference was maintained over several generations. Such resistance is not carried over into the eggs of the black scale as Swain and Buchner [111] found the resistance of black scale eggs to cyanide fumigation was influenced by locality and season. However, high concentrations of HCN may be used in the winter as winter eggs are less susceptible to the fumigant than summer eggs. Also, earlier season fumigation is recommended.

The use of methyl bromide as an insect fumigant has increased greatly during the last year. Methyl bromide has been used for fumigating insects of stored food products [100]; Japanese beetle grubs and adults on fresh fruit and produce [31]. Soil fumigation with methyl bromide has been successful for the Asiatic beetle grub [59] and the white-fringed beetle grub, *Pantomorus* [78]. Chapman [21] obtained excellent kill of *Rhagoletis pomonella* maggots in apples with the fumigant. Lange [76] found the chemical gave practically a perfect kill of the artichoke plume moth larvae within planting stock at standard dosages. Mackie and Carter [79] report the results of one season's activities in the industrial application of methyl bromide to Bartlett pear fumigation for codling moth larvae. Methods, equipment, factors influencing fumigation and the economical problem are discussed thoroughly.

Another fumigant which has been receiving attention is dichloroethyl ether. It has been used as a soil fumigant, for control of the pear thrips [73] and the larvae and pupae of the plum curculio [107]. The application of the chemical in mineral oil gave control of the corn earworm in sweet corn [90]. Other fumigants and their uses are ethylene dichloride emulsion for the peach borer [19]; paradichlorobenzene for the black peach aphis [20] and as a fumigant for the larvae of the black carpet beetle [25]. Schwardt and Lincoln [98] obtained excellent control of the larvae and adults of the alfalfa snout beetle in Northern New York by fumigating the soil with carbon bisulfide. Under the locality conditions (climatic and soil) which existed, carbon bisulfide was found to be more dependable than chloropicrin, methyl bromide, carbon tetrachloride, dichloroethyl ether or orthodichlorobenzene.

There has been a lack of reliable methods of and information on the testing of termite-proofing materials. In April the Termite Committee of National Pest Control [114] announced certain fundamental principles of operation necessary for the control of termite infestations in woodwork in buildings.

The use of soil poisons for control of the subterranean termites has been rapidly expanding. Hockenyos [68] found trichlorobenzene and polychloropentane to be much superior to the orthodichlorobenzene now commonly recommended. Sodium pentachlorophenate also was highly toxic and repellent but it is easily removed from solution by the soil. Sodium arsenite and sodium arsenate were the best of the inorganic compounds studied. Smith [106] Ohio State University tested ten organic compounds as soil poisons for subterranean termites. He found diphenylamine to be remarkably repellent and toxic. The compound was effective ten days after soil treatment as compared with the time-effective limit of 60 to 72 hours for orthodichlorobenzene.

Headlee and Jobbins [66] were able to protect wood in the soil from the common termite (*Reticulitermes flavipes*, K.) for more than a year by treating the soil with 0.05 pounds of acid lead arsenate per cubic foot. The results of this work indicate that investigators may have overlooked a cheap and practical method for control of termites.

MISCELLANEOUS

Certain so-called inert materials have a lethal effect on some insects when dusted on their bodies. The toxicity of the inert materials is attributed to their desiccating and mechanical irritating action on the insect. Against the rice and granary weevils, Chiu [23] found crystalline silica was more effective than magnesium carbonate, amorphous silica, bentonite, talc or walnut shell flour. Low relative humidity, and a decrease in particle size within a certain range, increased the insecticidal efficiency of the crystalline silica dust.

Most of the recent publications on the removal of spray residues have been on the washing of sprayed apples. Cryolite residues may be removed with dilute hydrochloric acid, boric acid, and sodium chloride at the proper temperature [74] while the technique for removal of nicotine residues from apples is improved by a wash of sodium silicate [18]. Fahey and Rusk [37] in their studies on the effect of fruit growth and weather on deposits of insecticides on apples found fixed nicotine to be less susceptible to weathering than phenothiazine, and lead arsenate was least susceptible of the three insecticides.

Neiswander and Morris [88] have brought up the question again of whether a toxicant might be added to a nutrient solution as a means of control for phytophagous mites and insects. The results of their studies have shown that when the selenium concentration of foliage approached 90 to 100 p.p.m. the red spider was practically eliminated, and 45 p.p.m. controlled the black chrysanthemum aphid. Although selenium is toxic to higher animals, the method offers an approach to pest control, particularly on ornamental plants.

A number of the papers which have been referred to, present information on the statistical analysis of toxicity data. Tattersfield [112], Potter and Hocking [92], Woodbury and Barnhart [127], Hansberry and Chiu [61], Steiner [108], and Bliss [6, 7], are the principal investigators who have recently submitted contributions on methods of testing insecticides and statistical analysis of toxicity data. Richardson [96] of Iowa has presented a very interesting publication on advances in entomology during 1939, and 1940.

Without a doubt some recent publications on insecticides have been missed but it is hoped that the field has been sufficiently covered to give you a realization of the advances which have been made during 1939 and 1940 in insect pest control.

SUMMARY

During the last two years a great amount of work on the properties and toxicity of chemical compounds as insecticides has been published. New insecticides have appeared and new uses of old insect poisons have been found. Lead arsenate does not decompose greatly under field conditions which is contradictory to reports of earlier investigators. The decomposition which does take place is caused by hydrogen sulfide in spray waters. A new arsenate combination is basic copper arsenate, which is toxic to various species of caterpillar. However, the insecticide has been reported as causing some foliage injury. The presence of water in the molecule of calcium arsenates influenced toxicity. The factor of particle size influenced the toxicity of lead and calcium arsenate, Paris green, cryolite and phenothiazine to codling moth larvae. The results indicated

that extremely small particles in an insecticide may not always be desirable.

Some of the fluorine compounds have been reported on as control measures for the corn borer, boll weevil, alfalfa snout beetle and the strawberry crown borer. Thallium salts were successful in controlling the fire ant. Tartar emetic is being used for control of thrips and red spider on flowers.

A new nicotine-tannic acid product has been prepared which is comparable to derris in effectiveness against the corn borer. Of the 550 organic compounds which were tested against the screw-worm, those containing the nitro group were among the most toxic. Other work with the organic compounds has shown that there is no marked correlation between toxicity to codling moth larvae and the groupings involved or their relative position in the molecule.

Pyrethrum loses its toxicity when ingested by the southern armyworm; the inactivation being caused by tissues and their products in the living larvae. Instability of pyrethrins in storage is due to the ketonic alcohol. The addition of an antioxidant will aid in prolonging the toxicity of pyrethrum sprays. A new compound (elliptone) has been isolated from roots of *Derris elliptica* and plants of genus *Annona* have been found to possess insecticidal properties. The deterioration of rotenone in storage is greater when mixed with alkaline dust diluents than when the diluents are neutral or acid. Derris or rotenone has been reported as a control for citrus whitefly, purple scale, pea aphid, cherry fruitfly and in an aerosol for mosquitoes and house flies.

Of the nitrophenols, B-butoxy-B′-thiocyanodiethyl ether was found to be quite toxic to the eggs of the bedbug, grain weevils, some pests of stored agricultural products, red spider and European red mite eggs. The best product which has been developed out of nearly one thousand materials as a mosquito repellent consisted of diethylene glycol monobutyl ether acetate, diethylene glycol monoethyl ether, ethyl alcohol, corn oil and perfume. The first constituent of the above compound has been found to be repellent to house flies. Other deterrents to insects which have been reported on are: mercuric chloride solutions, tetramethylthiuram disulfide, nicotine sulfate plus Bordeaux mixture or red cuprous oxide, calcium pitchate and copper pitchate. The addition of sweet substances as attractants has increased the toxicity of some insecticides to the codling moth larvae. For trapping lures, proteins have been reported for the Central American fruitfly; unfertilized females of two species of vine moth were attractive to males of the same species, and isoamylamine has been found attractive to male June beetles.

A number of publications have appeared on work with such fumigants as: hydrogen cyanide, chloropicrin, ethylene oxide, dichloroethyl ether, paradichlorobenzene, ethylene dichloride, carbon bisulfide and methyl bromide. Methyl bromide has been used for fumigating insects of stored food products, larvae in apples, Japanese beetle grubs and adults on fresh fruit and produce, artichoke plume moth larvae, soil fumigation for the Asiatic beetle grub and the white-fringed beetle grub.

Soil poisons for control of subterranean termites which have been reported are: trichlorobenzene, polychloropentane, diphenylamine, lead arsenate, sodium arsenite and sodium arsenate.

Seven publications are cited that contain information on the statistical analysis of toxicity data. The literature citations contain 129 references.

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